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PROGRESS IN ACOUSTIC TRANSDUCER DESIGN

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1. ABSTRACT

New technologies and new materials have changed the manufacturing process of measurement microphones within the past few years. The basic construction is internationally standardized, ensuring that the acoustic performance of the new generation of microphones is unchanged relative to the old types, but with improved long term stability and electrical performance.

2. INTRODUCTION

Modern measurements microphones have remained nearly unchanged since their invention almost 40 years ago [1]. The basic construction have now been internationally standardized ensuring a uniform interface to auxiliary equipment like preamplifiers etc. However, the advent, within the past few years, of new high technology materials have enabled the manufacturing of a new generation of measurement microphones with improved performance and long term stability. Also as the tolerances for high precision machining tools have been narrowed the production specifications have been tightened ensuring a better reproducibility. (Fig.1).

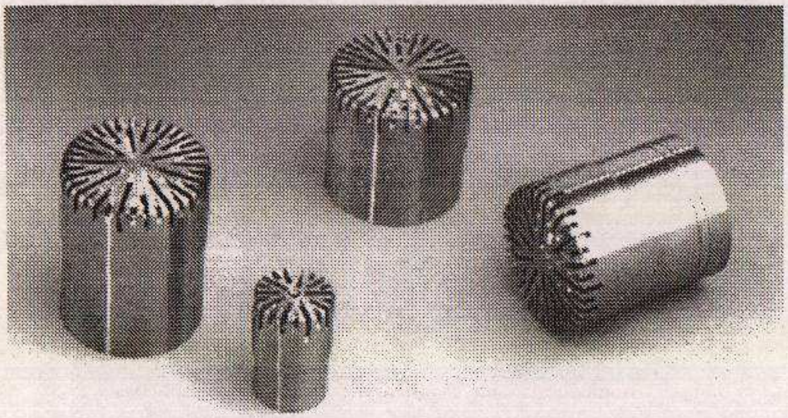

Fig.1 A new generation of measurement microphones

In order to maintain continuity, the basic performance of the new generation of microphones is unchanged relative to the old types. This means that the enormous amount of existing acoustical data, measured with the previously available microphones, can be directly compared and interchanged with data measured with the new generation of microphones. A gain in accuracy and reproducibility should improve the future database.

3. STANDARDS

Some of the basic characteristics of measurement microphones are to a large degree determined simply by their physical dimensions. These dimensions have been standardized in the international standard IEC 1094 "Measurement Microphones, Part 4: Specifications for working standard microphones" [2], and ensure that for example threads are uniform so that different types of auxiliary equipment, like preamplifiers, can be used on different types of measurement microphones. The standard defines three classes of microphones commonly referred to as 1", 1/2" and 1/4" microphones, (fig.2). As can be seen, dimensions such as the outer diameters of the microphone casings and the threads are precisely defined, while the length of the microphone is not specified. This means that the internal volume in the microphone can be optimized by changing the overall length of the microphone casing, depending on the type of microphone within a class.

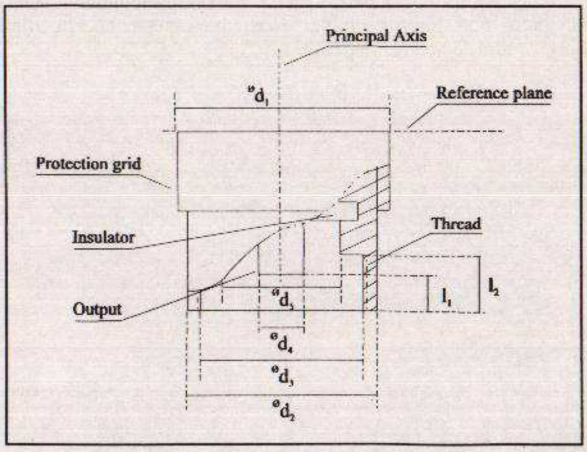

Fig.2. Standardized dimensions for measurement microphones.

Dimension Symbol	Type WS1P/F/D	Type WS2P/F/D	Type WS3P/F/D
$^{\bullet}d_1$	$23{,}77^{+0{,}05}_{-0{,}1}$	$13{,}2^{+0{,}05}_{-0{,}1}$	$7{,}0^{+0{,}03}_{-0{,}05}$
$^{\bullet}d_2$	23,77 ± 0,1	12,7 ± 0,1	6,35 ± 0,05
$^{\bullet}d_3$	23,11	11,7	5,70
$^{\bullet}d_4$	4 - 6	3 - 5	2 - 3
$^{\bullet}d_5$	> 12,2	> 7,8	> 3,5
l_1	3 - 4	3,6 - 4,6	1 - 2
Length of thread l_2	> 2,7	> 2,2	> 1,6
Thread $^{\bullet}d_3$	60 UNS-2B	60 UNS-2B	60 UNS-2B

Table 1. Standardized dimensions for measurement microphones

While the IEC 1094 standard determines the dimensions for measurement microphones, the performance of the microphones are normally related to the ISO Standard 651 'Sound level meters' [3], or the corresponding ANSI S1.4 [4]. As these are generally accepted standards for acoustical measurements, they have ensured the creation of a homogeneous database of acoustical measurement results throughout the world. It is important, however, to notice that these standard does not give specifications for the microphones themselves, but specifies the requirements for the full measurement system, including microphone, preamplifier and analyzer or sound level meter. This means that, when for example ISO 651 specifies that the frequency response should be within ± 1dB for a Type 1 Sound level meter, in the frequency range from 100Hz to 4kHz, then it is not enough that the microphone in itself satisfies this conditions. The conditions have to be fulfilled for the total measurement system and therefore the requirements for the microphone itself is stronger. Although measurement microphones are often stated to be of Type 1 if they themselves fulfill the requirements, this will allow for no additional tolerances for the rest of the instrumentation. Therefore the requirements for the individual components should be tightened relative to the ISO 651 requirements, so that the overall system will be within the requirements.

For many applications the use of windscreens are mandatory. It is obvious that the accuracy of the measurements are influenced by the windscreen. It is also important to keep the proper reference direction in mind. An outdoor microphone may be used for aircraft fly-over noise monitoring and should therefore have reference direction 0° or upward. A community noise monitoring microphone should be specified with reference direction in the vertical plane and for both applications the microphones should be measuring correct with windscreen.

It is common practice to specify tighter requirements for type approval of individual components, such as microphones, which will be incorporated in to a measurement system. A typical example is for an Outdoor Microphone Unit, Fig.3, for permanent noise monitoring. Such a system would be required to fulfill the ISO 651 requirements for a Type 1 sound level meter. To ensure this the Outdoor Microphone unit as a stand alone unit is specified to be within ± 0.7dB in the frequency range from 100Hz to 4kHz. When the unit is then connected to an analyzer or sound level meter, which have been type approved with similar stringent requirements it is ensured that the total measuring system fulfills the ISO 651 requirements.

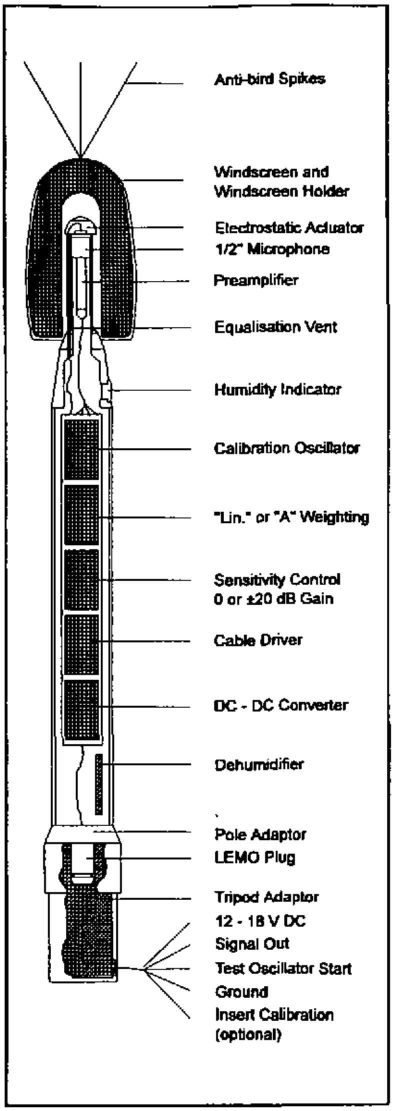

Fig.3. Outdoor Microphone Type 41AM, built to IEC 651 system requirements

4. CONSTRUCTION

The basic construction principle of measurement microphones have remained the same for the last 40 years. The measurement microphone consists of basically 5 elements: the protection grid, microphone casing, diaphragm, backplate and insulator, see Fig.4. The diaphragm and the backplate form the parallel plates of an air capacitor. This capacitor is polarized with a charge either from an external voltage supply (externally polarized type) or by an electrical charge injected directly into an insulating material on the backplate (prepolarized type). When the sound pressure in a sound field fluctuates the distance between the diaphragm and the backplate will change and thereby change the capacitance of the diaphragm/backplate capacitor. As the charge on the capacitor is kept constant, the change in capacitance will generate an output voltage on the output terminal of the microphone. The acoustical performance of a microphone is determined by the physical dimensions such as the diaphragm area, the distance between the diaphragm and the backplate, the stiffness and mass of the suspended diaphragm and the internal volume of the microphone casing. These dimensions have over the years been kept constant and thus the acoustical properties of the microphones have been preserved.

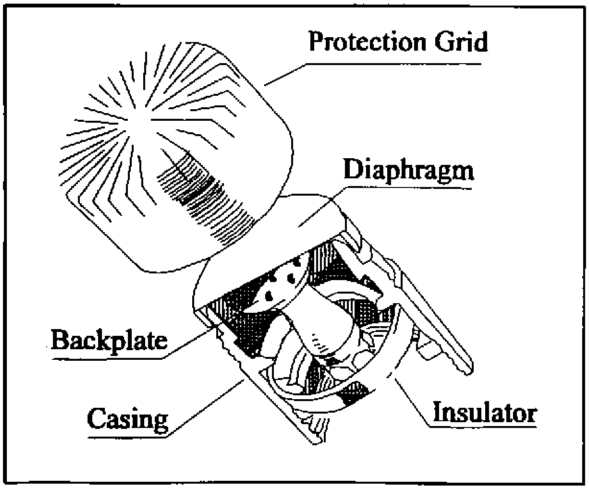

Fig. 4 Basic elements of measurement microphone

The environmental properties of a typical measurement microphone, such as temperature stability, long term stability and insensitivity to rough handling, is on the other hand determined mostly by the choice of materials and assembling techniques. Traditionally the microphone diaphragm has been made of a nickel alloy, which was electrogalvanic deposited on a highly polished base material. This resulted in a compromise between a brittle and a ductile diaphragm and also less corrosive resistant diaphragm, than could be made from stainless steel. Despite this, the nickel diaphragm was preferred, because stainless steel materials were rolled during the production process and therefore had different mechanical properties parallel to and perpendicular to the rolling direction. Also stainless steel diaphragms had problems with varying thickness and stiffness, and occurrence of pin-holes. This has been changed with the advent of new extreme high-quality, isotropic stainless alloy materials. These has maintained the good properties of nickel and at the same time improved the corrosive resistance and mechanical durability of the diaphragm. Furthermore it has made it possible to mount the diaphragm on the microphone casing with a heat-shrinking technique rather than traditional thread method. As the nickel was brittle and very ductile it was necessary to screw the diaphragm on to the casing. The inherent tolerance in the thread made the assembled microphones susceptible to mechanical shocks, so that the acoustical characteristic of the microphone would change.

With the improved assembling technique the microphones have become much more resistant to mechanical shocks. The typical result of a mechanical shock to a conventional measurement microphone, is a slight change in the sensitivity of for example 0.2 dB. This change may be proved simply by checking the sensitivity of the microphone with for example a pistonphone and compare the result with the value stated on the Calibration Chart. This simple test will however not reveal anything about possible changes in the frequency response. Even if the sensitivity at the typical calibration frequency of 250Hz has only changed by a small amount, the changes at higher frequencies like 10kHz may be much more dramatic. The effect of small changes at higher frequency is especially critical for a set of sound intensity microphones. For a typical Type 1 sound intensity microphone pair, the phase difference between the two microphones must be less than 0.015° at 250Hz. To achieve this, it is necessary that the frequency responses for the two microphones at higher frequencies are very similar. In particular the diaphragm resonance frequency must be the same for the two microphones and even a small change in the resonance frequency of one of the microphones, due to a mechanical shock, may completely change the phase characteristic at low frequencies. Therefore the improved resistance to mechanical shocks obtained with the new materials and assembling techniques are extra important for intensity microphones.

Also the use of stainless steel protection grids, with improved high frequency acoustical transparency, instead of brass protection grids, as has been common in the past, adds extra protection to the microphone diaphragm against physical damage when dropped on a hard floor. The most common fatal damage in the past to measurement microphones dropped on the floor would be that the protection grid would be deflected inwards and pinch the diaphragm. Traditionally the protection grids has been produced in brass in order to reduce the price, but with new machining techniques the price difference between a brass grid and stainless steel grid is negligible compared to the advantages.

5. MICROPHONE CALIBRATION

Primary calibration of measurement microphones is carried out by reciprocity technique. Secondary calibration is carried out by use of a transfer standard, transferring the sensitivity from a primary calibrated microphone to a secondary standard. This is most reliably done at 250Hz. At higher frequencies the uncertainty of the transfer coupler and the microphone response starts to influence the results. 1000Hz is often used for convenience, because the electronic weighting of A - C - D etc. are referred to 1000Hz. However, for acoustic accuracy 250Hz is the best choice, because it is equally far from the low frequency problem area caused by air-equalization and leaks and the high frequency problems caused by wave motion in couplers and microphone diaphragm damping.

The frequency response is seldom causing problems, if the sensitivity at 250Hz is unchanged. The frequency response is by far best determined using electrostatic actuator technique, provided the electrostatic actuator is properly designed. The use of combined protection grid and actuator may cause errors, both in the actuator response and for the free-field correction and directional pattern at high frequencies. Many calibrators are less reliable than the microphone-preamplifier-sound level meter combination. If the calibration shows a need for adjustment, a careful evaluation of the cause for correction should be carried out: Has the calibrator changed? Or the microphone or the sound level meter indication? A calibrator consists of a source, a generator, an amplifier and sometimes of a built-in reference, which is seldom of the same quality as the measurement microphone. Many calibrators should only be used as go - no go decision devices, not for adjusting the sensitivity of the sound level measuring instrumentation.

The accuracy of sound level measuring devices is often more influenced by the operators knowledge about acoustic measurements, than by the variability in good instrumentation. This is especially true for external polarized microphones, while pre-polarized microphones may be more prone to sporadic changes of a few dB.

References :

[1] G. Rasmussen, "A New Condenser Microphone", Brüel & Kjær *Technical Review*, No. 1, 1959.

[2] IEC Standard 1094 "Measurement Microphones", Part 4 : Specifications for working standard microphones

[3] ISO Standard 651 "Sound level meters"

[4] ANSI S1.4 - 1983 "Specification for Sound level meters"